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Nutrition in isolation: Challenges, real-world example, and pathways to robust research

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Isolated and confined environments, such as spaceflight analogs or Antarctic research stations, offer the opportunity for a unique type of nutrition research. The logistical, psychological, and methodological hurdles, lead to adaptations specific to unique extreme environments. To maintain the health and performance of a crew, it is important for trained nutrition scientists to decipher the nutritional requirements under these conditions. That knowledge will also be fed into the design of robust, palatable, psychologically sustainable, and resource-efficient food systems of sufficient variety.

Unfortunately, we often see the small number of participants from isolation studies hindering researchers from reaching statistically robust conclusions about the physiological or behavioral adaptations observed. It is the nature of nutrition science and of human adaptations to include a high degree of interindividual variability, and single outliers can disproportionately affect our research outcomes. However, careful dietary planning can bring about measurable physiological benefits, even with a limited sample and duration, as demonstrated by Douglas et al. [1]. Specifically, the research showed, that a diet rich in sources of flavonoids and omega-3 fatty acids, such as vegetables, fruits, and fish, when compared to a standard diet, sustains improved immune profiles, low cortisol levels, and stable gut microbiome profiles [1].

Nonetheless, a strictly monitored dietary compliance is quite uncommon in isolation missions. As I have experienced, not only as a researcher but as a crew member myself, it is impossible to prevent the participants from diverging from their prescribed plans, be it because of satiety levels, mood, preferences, or even logistics disruptions. Accurate, precise, and consistent tracking of meals is time-consuming, burdenful, and tedious, and it still fails in the case of mixed meals, database limitations or even unreliable recalling, leaving a gap between actual and planned nutrient intake. Unless the intake is measured in real-time via weighted food records or validated digital food logs (which however remain time-consuming, burdenful, and tedious), any associations between dietary intake and physiological outcomes remains speculative.

Could we lean into standardized food items to solve this problem? Unfortunately, the already limited variety and freshness of food is creating major problems for nutrition in isolation. Shelf-stable food item options are usually thermally processed, freeze-dried, or rehydratable. While they offer adequate sustenance, the palatability of these items is reduced, their texture foreign, and their micronutrient content severely affected by the processing and the storage. Meal replacement bars were used by Sirmons et al. instead of breakfast, as a strategy to reduce system mass and packaging waste [2]. The findings demonstrated that this substitution led to decreased energy intake, lower acceptability, mood disturbances, and signs of neurobehavioral vulnerability [2]. Thus, there is support to the notion that the function of food, especially in isolated environments, extends beyond that of mere subsistence, leaning heavily into that of a mental and behavioral stabilizer.

Numerous psychological studies support the idea that this interaction between food and emotional state is two-sided. An individual's emotional state can modulate food intake, perception, and even digestion, threatening to create a negative feedback loop between the stressful conditions of the isolated environment and the entire eating experience. It is likely that the interaction between mood and food goes beyond appetite regulation, and it includes perception of taste, texture, and satisfaction. Inadequate food and nutrition have been identified as one of NASA's top "red" risks for long-duration spaceflight by Patel et al., with compounded effects on cognition, emotional well-being, and a range of physiological systems such as immune function and metabolism [3]. This places nutrition in a key position for effective countermeasure development.

In this context, we turn to the gut microbiome: highly sensitive to both diet and psychosocial factors, it emerges as physiological mediator. In their longitudinal study on Antarctic expedition teams, Lee et al. observed that cohabitation and shared meals led to convergence in gut microbiome profiles among unrelated individuals, nevertheless leaving functional pathways unaffected [4]. This research highlights the profound effect that shared environment and diet can have on gut health, and possibly by extension, immune and cognitive function.

Despite these established connections, many commercial and smaller-scale missions lack methodological rigor. During the ASI-ITALIAN NAVY-ESA workshop in 2025, some of these issues were highlighted through the information given on the nutrition of the 2024 Astroland mission crew (a 4.5-day-long Mars analog mission in a cave habitat). Five female participants engaged in structured extravehicular activity and consumed freeze-dried meals and emergency rations. While daily menus were provided, adherence or precise documentation was not enforced. Participants filled out post-meal questionnaires focusing on mood, satiation, perceived taste, and self-reported percentage of portion consumed. Although correlations were found between taste and percentage consumed ($r = .578$, $p < .001$), and mood and satiety ($r \approx .45–.49$, all $p < .001$), the absence of validated tools severely limits the generalizability of the results. There was no objective verification of energy or nutrient intake, and the psychological assessments did not use established instruments. Moreover, there are no subsequent studies where similar methods have been applied, in order to ensure reproducibility and a larger data set. This case exemplifies how even well-intentioned missions may yield data that are difficult to interpret or compare, reinforcing the need for methodological harmonization across analog missions.

Another issue observed is the omission of data that, while extending beyond nutrition, are profoundly relevant to the development of countermeasures. Nutrition does not act in isolation from other factors; it is interconnected, among others, with psychological state and with the microbiome. Deciphering these relationships can lead to the development of more holistic countermeasures that would tap into synergies to yield improved results. However, we see frequently limited applicability of research data to advanced research questions. One example is the EXEMSI campaign by Milon et al., which produced valuable data on caloric intake and macro- and micronutrients in confinement, but did not extend to the capture of psychological and microbiome data, creating a blind spot [5].

There is a wide range of validated assessment instruments that can be used to address these gaps. The Council on Nutrition and Appetite Questionnaire (CNAQ) offers a structured approach to tracking appetite changes under stress. The Adult Eating Behaviour Questionnaire (AEBQ) is suitable for the measurement of appetite traits. The Food Craving Questionnaire-Trait (FCQ-T) is designed to capture cravings that emerge in response to emotional or environmental cues. Together, these tools can help us distinguish between biologically driven intake and mood-driven eating behaviour. The Self-Regulation of Eating Behaviour Questionnaire (SREBQ) is an instrument that can give insights regarding an individual's capacity to regulate their own eating habits. In addition, the evolution of dietary patterns over time can be captured via food frequency questionnaires and digital food records, while behavioural eating patterns can be recorded with the aid of structured food diaries, enriched with additional information on time and setting of the meal, as well as the emotional state. Lastly, post-prandial mood and sensory scales can help with the accurate representation of food experiences and compliance. However, standardization remains a major challenge for agencies and commercial analog environments alike. As there is no systematic use of assessment tools, the findings are not comparable across missions, delaying the development of comprehensive nutritional countermeasures.

In summary, the nature of nutritional research in isolation is complex, affected by individual behaviour, logistics constraints, and emotional status. However, what holds progress back is not necessarily the complexity, but the inconsistency in methodologies, the lack of validated tools, and the poor data standardization. Given the importance of nutrition not only as sustenance, but also as a factor of emotional balance, microbial stability, immune competence, and psychological resilience, it should be a priority as we prepare for long-duration missions. Through the use of validated tools, open data platforms, and shared standards, we can ensure that, no matter the size sample or the setting, each and every mission is contributing constructively to the formulation of a consensus about the adaptations of the human body in isolation, and about the optimal nutrition strategies.

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